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Development, implementation and evaluation of an information model for archetype based user responsive medical data visualization

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ABSTRACT

Background: When medical data have been successfully recorded or exchanged between systems there appear a need to present the data consistently to ensure that it is clearly understood and interpreted. A standard based user interface can provide interoperability on the visual level.
Objectives: The goal of this research was to develop, implement and evaluate an information model for building user interfaces for archetype based medical data.
Methods: The following types of knowledge were identified as important elements and were included in the information model: medical content related attributes, data type related attributes, user-related attributes, device-related attributes. In order to support flexible and efficient user interfaces an approach that represents different types of knowledge with different models separating the medical concept from a visual concept and interface realization was chosen. We evaluated the developed approach using Guideline for Good Evaluation Practice in Health Informatics (GEP-HI).
Results: We developed a higher level information model to complement the ISO 13606 archetype model. This enabled the specification of the presentation properties at the moment of the archetypes' definition. The model allows realizing different users' perspectives on the data. The approach was implemented and evaluated within a functioning EHR system. The evaluation involved 30 patients of different age and IT experience and 5 doctors. One month of testing showed that the time required reading electronic health records decreased for both doctors (from average 310 to 220 s) and patients (from average 95 to 39 s). Users reported a high level of satisfaction and motivation to use the presented data visualization approach especially in comparison with their previous experience.
Conclusion: The introduced information model allows separating medical knowledge and presentation knowledge. The additional presentation layer will enrich the graphical user interface's flexibility and will allow an optimal presentation of medical data considering the different users' perspectives and different media used for data presentation.

1. Introduction

In the healthcare domain the prevalence of electronic health records (EHR) is growing rapidly. The archetype model of ISO 13606 provides a means for modeling medical content and for defining knowledge for the electronic exchange of health records [1]. Semantic interoperability does, however, not stop when the data have been successfully exchanged between systems [2]. Once transferred the data have to be presented consistently to ensure that it is clearly understood and interpreted [3,4]. A standardized user interface can provide interoperability on the visual level [5,6].

Visualization is defined by Gershon et al. as "the process of transforming data, information and knowledge into visual form making use of humans' natural visual capabilities" [7] while Card et al. define visualization as "the computer-assisted use of visual processing to gain understanding". In our research we add to this by defining data visualization as a process of consecutive transformation of domain knowledge into a user operable interface where each step adds new knowledge to the definition of a user interface, which is "the system by which users interact with a machine" [8].

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Wide acceptance of medical data standards [9–11] caused need in finding efficient visualization methods mostly for archetype based standards (ISO 13606, openEHR) [12,13]. The standards employ a dual model approach to express medical knowledge. The reference model captures the global characteristics of medical records. It defines generic building blocks for aggregating health record components and for collecting the context information required to meet ethical and legal requirements. A hierarchical structure accommodates the separate parts reflecting the organization of medical records. The single building blocks are specified as follows. EHR_EXTRACT is the top-level container for the complete patient EHR or parts thereof. FOLDER is an optional organization element that divides content into compartments. COMPOSITION represents an encounter or document that may contain SECTIONs that provide clinical headings. The ENTRY represents a clinical statement that has ELEMENTs, i.e. the concrete data values that may be contained within CLUSTERs for organizing data structures like tables. All the building blocks within an EHR_EXTRACT have common attributes including a persistent unique identifier, a clinical name labeling each part, a standardized coded concept and the identifier of an archetype node.

The archetype model provides meta-data used to define patterns for the specific characteristics of the clinical data. Archetypes are formal definitions of combinations of the building blocks defined by the reference model for particular clinical organizations or settings. They express distinct clinical concepts by specifying a particular hierarchy of record components and define or constrain names and other relevant attribute values, data types and value ranges. The Archetype Definition Language (ADL) is a formal syntax for the definition of archetypes. It provides a general description of the concept specified and includes terminologies and translations. Archetypes deliver meta-data that consistently define the diverse, complex and frequently changing concepts in clinical practice and, thus, facilitate semantic interoperable EHRs. Based on this principle any part of a medical record can be interpreted faithfully even if the structure and nature of the clinical content had not been agreed in advance.

The complexity of the approach can be hidden from the user. Appropriate archetype editors assist in the creation of archetypes and give support through a user-friendly graphical editor. The main issue of archetype based visualization methods is that the structure of an archetype does not provide (and in fact it should not) the information necessary to build an optimal presentation layer [14,15]. The modeling functionality provided by archetype model allows building a medical document of any complexity.

Various approaches for data visualization, such as the model-view-controller (MVC) paradigm [16], have been developed. Within the MVC paradigm the task of visualization is being related to the modeling of the view, which does not define the exact presentation layout but renders the model (i.e. ISO 13606 or HL-7 CDA data model [17]) into a form suitable for building a GUI. This approach allows different views for one model, the importance of which will be shown later.

Bull [18] developed Model Driven Visualizations (MDV), a model-based approach to generating interfaces. These visualizations are applied by mapping or transforming a software data model to the visual model. Among medical data visualization projects that use this approach we can name LifeLines project, The PropeR project, Gastros Project, MUDR EHR. The Proper project developed a visualization method based on the simplified version of ISO 13606. The Gastros developed a method for the dynamic creation of user interfaces based on the openEHR archetype model. The MUDR project was to develop a set of web-based, highly interactive graphic modules that process standard based medical data. These projects developed efficient visualization solutions. The shortcomings of the projects are mostly related to the structure of the current medical concept specifications. The current methods that allow the most generality and re-usability are based on the archetype data model of ISO 13606 and openEHR. However, the visualization methods that are based on the data structure do not produce an optimal presentation layout. They use ADL definitions of the archetypes to generate presentation templates. This complicates the process of visualization properties definition. This does not allow the user interface to be really generic and to work without manual data addition and adjustment of the layout.

Our project advances the research on the standard based medical data visualization. We introduce a dual layer XML based approach to the definition of archetypes and their visual layout that will allow automatic generating of efficient medical data interfaces.

The goal of this paper is to propose, develop, implement and evaluate an information model and a specification for building a user interface for archetype based medical data.

2. Methods

EHR systems must offer multi-client (e.g. doctors, nurses, patients) and multi-media GUIs (e.g. desktop, smartphone, touchpad, television) [19–21]. This means that the visualization method must make sure that the same software can provide different interfaces for different devices and users.

Irrespective of the purpose of the displayed information, the presentation of information will use the following four types of presentation knowledge [12,13,22–24]: medical content related attributes, data type related attributes, device-related attributes, user-related attributes.

2.1. Medical content related attributes

The simplest display properties of the data are related to a data type. Archetypes may contain data that are not required in the context of every use role.

2.2. Data type related attributes

There is a certain set of data types [25] available in the ISO 13606 reference model. Data type related presentation attributes links presentation behavior to the constituents of the information structure.

2.3. Device-related attributes

A large range of devices can be used to access one EHR system. These include tablet PCs, PDAs, smartphones. The data must also be nicely presented when printed.

2.4. User-related attributes

Currently healthcare professionals are the main users of EHRs [26,27]. However, there are strong indications that the involvement of patients will improve healthcare. Personalized access to the patient's electronic health record will support patient empowerment [28–30]. Therefore, when specifying a GUI it is necessary to take into account the requirements of the different user groups.

3. Evaluation

The developed method was implemented as a module of an existing EHR system to prove the concept and to evaluate the feasibility of the developed approach. The results were evaluated in a clinical environment [31–33]. The chosen evaluation approach was based on the Guideline for Good Evaluation Practice in Health Informatics (GEP-HI) [34,35].

We investigated the following properties of the method:

- Ability to define reusable graphical representations for EHRs.
- Ability to address different user groups and presentation media by providing flexible and adjustable graphical user interfaces.

Research questions therefore were:

Does the BMC visualization method support multiple views on the medical data?
Does the BMC Visualization improve the patients' understanding of EHR data?
Does the BMC Visualization decrease the time of reading the EHR for doctors and patients?

3.1. Description of the pilot site

The proposed visualization method (let's call it BMC Visualization) was evaluated in Tomsk, in the Municipal Polyclinic #2. The daily average load of the polyclinic is 460 patients.

The study involved 30 patients, 3 general practitioners and 2 specialists.

Since the first implementation of EHR Avrora was made in 2010 the doctors and some of the patients had experience in operating the software. The system provided the patients with the following functionality:

1. Web-based appointment system
2. Web-based access to the personal medical data

The patients could use these functions at home or at the polyclinic using an information kiosk.

3.1.1. The study team

The study team consisted of persons representing Helmholtz Zentrum München (HMGU) – 2 specialists, UMSSoft – 5 specialists, Tomsk Polytechnic University (TPU) – 5 specialists.

The expert group that performed the evaluation combined the competences of the practicing doctors and system analysts. The doctors had an experience of operating the EHR.

3.1.2. Security, privacy, ethical and legal aspects

The ethical committee of the Tomsk region as well as the Polyclinics' data protection officer received a detailed description of the study and the informed consent form. The privacy of any participating person was respected at any time.

3.1.3. The evaluation phase

The evaluation started on the 27th of May and finished on the 27th of June 2013. The process of the results' analysis started during the evaluation and was finished 2 weeks after having finished the evaluation.

3.1.4. Evaluation criteria definition

The evaluation criteria and metrics were defined based on the evaluation objects, research questions and the commonly accepted evaluation methods derived from the previously published evaluation studies and software quality standard (ISO/IEC 9126 Software engineering – Product quality) [42–49]. The criteria were defined to answer the research questions. Then they were grouped and broken down to facilitate the evaluation (Fig. 1).

To group the criteria that corresponded the research questions we used the standard ISO/IEC 9126-1. Criteria groups are shown

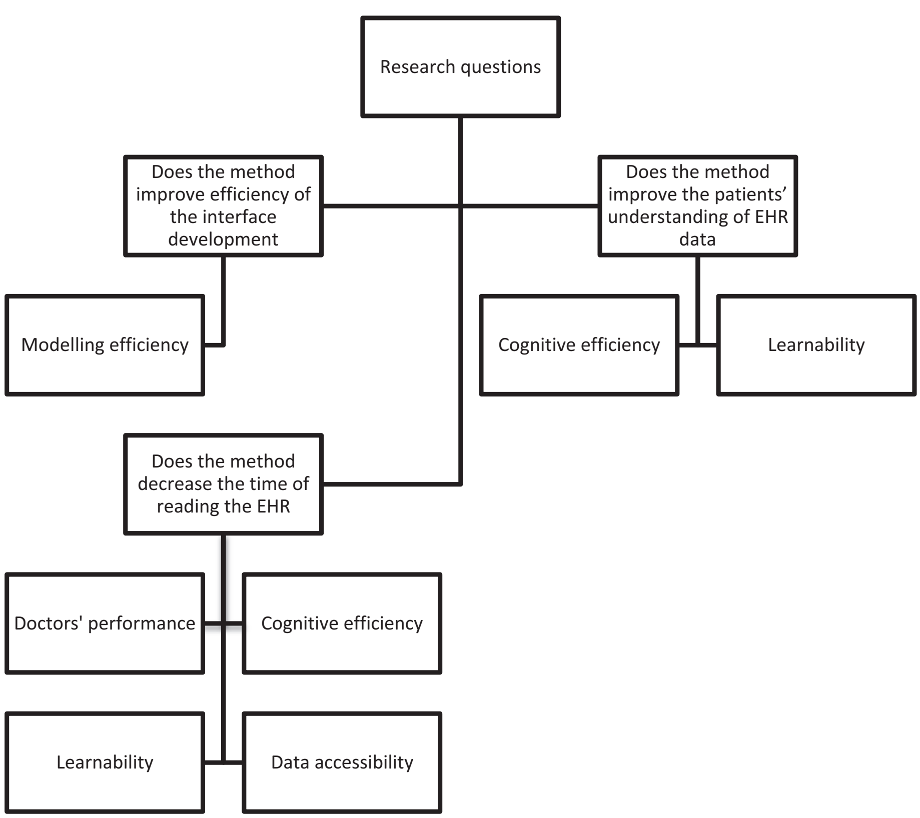

Fig. 1. Evaluation criteria definition.

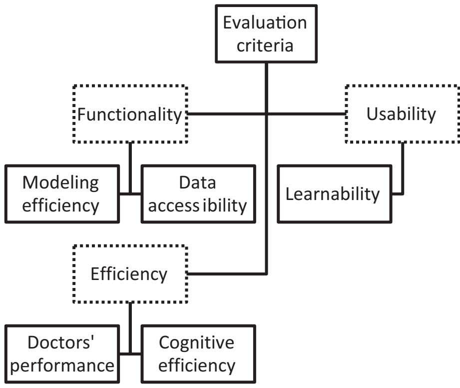

Fig. 2. Evaluation criteria classification.

in dotted lines in Fig. 2. The criteria are derived from Fig. 1. The quality model presented in the first part of the standard classifies software quality in a structured set of characteristics and sub-characteristics as follows:

1. **Functionality** – A set of attributes that bear on the existence of a set of functions and their specified properties. The functions are those that satisfy stated or implied needs.
   a. **Modeling efficiency** is important when we are in need for a constant change of medical documents.
   b. **Data accessibility** tests if the users can access personal medical data using different tools. In our case information kiosk in the polyclinic and home web-access.
2. **Efficiency –** A set of attributes that bear on the relationship between the level of performance of the software and the amount of resources used, under stated conditions.
   a. **Cognitive efficiency** A software system should be designed to reduce the cognitive load experienced by users. In alignment with tasks the user is attempting to accomplish, appropriate information should be displayed; graphics and visualizations used effectively, and clutter should be reduced or eliminated.
   b. **Doctors‘ performance** refers to the increase of the performance compared to the previously used EHR system and paper based documents.
3. **Usability** – A set of attributes that bear on the effort needed for use, and on the individual assessment of such use, by a stated or implied set of users.
   a. **Learnability** in software testing learnability, according to ISO/IEC 9126, is the capability of a software product to enable the user to learn how to use it.

3.2. Evaluation process

The evaluation process was based on the evaluation of the metrics (that are evaluated within other criteria) several times, comparing the progress of the users. The obtained preliminary results were processed using statistical methods [36,37].

The evaluation metrics and the evaluation process are presented in Appendix A.

4. Results

We introduce a visual medical concept (VMC) that will complement the archetype layer with a presentation layer, separating medical domain model (ISO 13606) from presentation model (VMC). As shown in Fig. 3, a visual medical concept contains the data to implement a presentation layer for archetype based

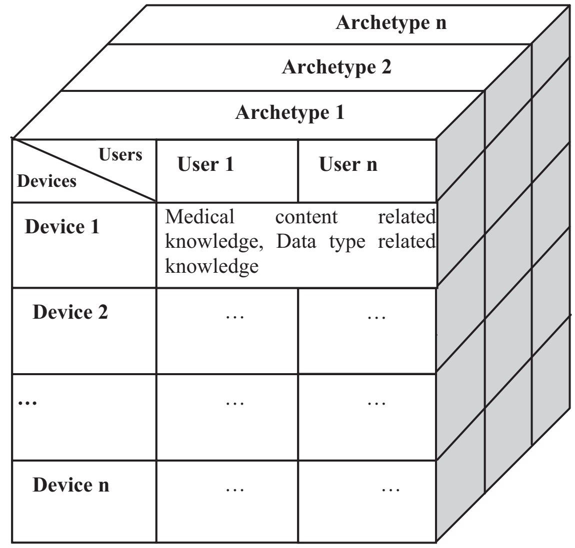

Fig. 3. Multi-dimensional visual medical concept structure.

medical data. The visual layer can contain data from different archetypes (archetype slice) and can be specified for different users (user slice) and media (device slice).

The visual medical concept sorts the medical content in visual groups. The visual groups may combine data fields from different archetypes. The data fields are grouped to be able to define the presentation properties for the whole group so that different medical concepts can be presented as one medical document (i.e. blood test consisting of different parameters). Application of visual groups allows:

- Processing grouped data fields as one entity for building graphics or tables.
- Assignment of properties to the entire group (user related, device related knowledge).

The visual medical concepts define platform independent visual blocks to specify a layout for each archetype data field and to group different archetype elements into visual groups. Each visual group contains a specification of visual tools that can be used to build a user interface. The archetype structure provides only the basis of a visual document (e.g. compositions, entries, data types). This allows building a visual layer based on the ISO 13606 archetype model that will take into account the different perspectives on the medical data of doctors and patients.

The developed visual medical concept meets the following requirements [35]:

1. Complies with the requirements and constraints of an ISO 13606 reference model.

The dual model approach of ISO 13606 allows separating the medical knowledge from the software implementation and permits healthcare professionals to define medical concepts without the need to understand how the concepts will be implemented within the EHR.

2. Provides multiple device support.
3. Supports different views on the same data.

The same information can be displayed in different ways according to its needed context. This feature is useful for healthcare professionals who may need different views according to their specialization. Patients will need less data but the data have to be presented in more convenient form to ensure that in will be understood without medical background.

4. Is stored separately from the visualized data.

The dual model approach that is used as the basis for archetypes has proven to be efficient and flexible.

5. Is platform independent.

A platform independent concept will allow flexibility and easy adaptation.

4.1. Visual medical concept implementation

Archetypes are hierarchical structures and support an XPath-like definition to access substructures [30,38]. An XML schema for visual medical concepts was developed considering the archetype model of ISO 13606 to ensure a full compatibility with archetypes. Each visual medical concept is stored as XML file.

A visual medical concept is logically divided into three main sections: metadata, visual content and visual layout. The metadata section specifies the properties of the VMC. The visual content section defines the data fields that are included in the VMC. The data fields are derived from different archetypes and combined into visual groups. Visual groups are processed as one entity when the GUI is being built. The visual layout section specifies the presentation properties of the GUI elements. The VMC allows specifying the user groups and the media for each element.

The XSL templates provide a platform-independent description of the actual display of the visual concept, for example, an HTML page. Templates implement the concept of different views on the same data. The hierarchy of models is presented in Fig. 4.

The visual model is based on the archetype model of the ISO 13606. On the instance level there are archetypes that define medical knowledge (structure and semantics of the medical concepts i.e. blood test consists of 5 elements each of them has value units and reference) and visual medical concepts that define corresponding presentation knowledge (i.e. blood test must be presented to the user as a table with red text for the values that are not within reference). Visual medical concepts add a detailed description of visual properties of each archetype data field. A VMC combines and organizes data fields of an archetype into visual documents.

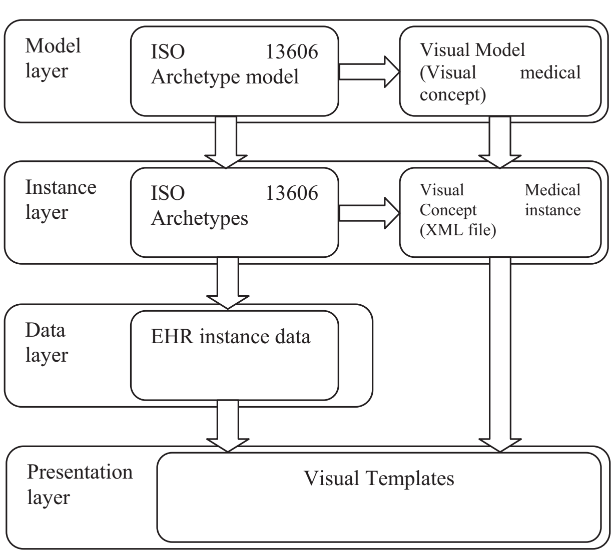

Fig. 4. Medical data visualization definition scheme.

In our projects we used XML Schema to model the archetypes instead of Archetype Definition Language (ADL) [39]. On the data level VMC files with specified content and presentation properties are associated with corresponding XML data files (i.e. EHR instances with actual levels of the blood test). This combination is used by the visual templates to build the user interface. To present the medical document an EHR System applies a predefined XSL Template. The template analyses the visual medical concept file and defines the following parameters:

- Visual document content.
- Data source files.
- Data fields.
- Visual groups (group different medical concepts).
- Visual document layout (specifies presentation properties for the medical concepts).
- Presentation type (diagram, table, etc.).
- Users and devices that this view is available for.

XSL templates are used in the proof of the concept web-application and are not the part of the developed information model.

5. Implementation

A Web application was built using XML, XSL and C#. The Web application can display archetyped medical data collected from different sources and generate reports conforming to various archetypes based on the approach described above. The medical data are offered to the system as XML structures.

The following example describes the components and the processes that lead to the display of the medical data on a user's desktop. When the application calls medical data, a template generates the interface for the medical document. It looks for the referenced archetypes in the specified archetype repository. Then it analyses the data repository to find the data instances that correspond to the archetype. A similar mapping process is executed to find an appropriate visual presentation for the data that is specified within the visual medical concept. The process is based on the targeted device and the user group. This mapping process is performed from specific presentation options to generic ones. All elements are combined to display the medical data on the user's device. XML notation is used to structure the data. Paths are expressed in XPath notation.

5.1. Archetype set

In the ByMedConnect dataset an archetype of laboratory results is represented as a set of archetypes of a similar structure. Each archetype contains one ELEMENT of type Physical Quantity (PQ) consisting of a value (the measurement result) and a unit, marked with a name (e.g. "Leukocytes"), one ELEMENT of type PQ interval that contains the reference interval for the measured parameter and one ELEMENT of type DATE for the date of measurement (Fig. 5).

The content of the blood test report is specified in the **visual content** section of a VMC (Medical content related attributes) and consists of a set of visual elements (Data type related attributes); each referring to the corresponding archetype. The presentation features of the concept are specified in the **visual layout** section of the visual medical concept.

5.2. Visual content section

The laboratory report represents a set of blood parameters grouped in a table where each parameter is a row and dates are

```xml
<items>
  <ITEM xsi:type="ELEMENT">
    <name>
      <originalText>Leukocytes</originalText>
    </name>
  </ITEM>
  <ITEM xsi:type="ELEMENT">
    <name>
      <originalText>Reference-Leukocytes</originalText>
    </name>
    <value xsi:type="IVL_PQ">
      <high>
        <value>50</value>
        <units>...</units>
      </high>
      <low>
        <value>10</value>
      </low>
    </value>
  </ITEM>
</items>
```

Fig. 5. Archetype definition.

columns. Each parameter is stored in a separate XML file. It may come from different sources, while the doctors require these parameters to be grouped in one report (Fig. 6). This is done by specifying the VMC file as XML document where the data is stored and the XPath of the data fields is defined. Visual content section contains User-related attributes under a “Users” tag and Device-related attributes under a “Devices” tag. A “User” tag at the moment can contain the following values: “doctor”, “patient” and “doctor and patient”. A “Devices” tag at the moment can contain the following values: “desktop” and “mobile”.

5.3. Visual layout section

View section defines the visual composite to be applied (i.e. table, diagram) for each visual group. A table, the most common way of displaying the laboratory results, is defined by default in the “VisualSpec” tag. The visual medical concept allows multiple view definitions. One visual group will be shown to users in three different ways as specified in the VMC (Fig. 6).

5.4. Templates

An XSL template was developed to produce a medical document specified as VMC as a web-page. The template is capable of building a web-page for any valid VMC.

According to parameters the specified in the VMC the system builds a visual document. In Fig. 7 different views of the results of laboratory tests are shown. The following main parameter differs for these pictures: visual presentation type (table, one graphic for each parameter, aggregated graphic). This was specified in the “visual spec” part of the “visual group” section.

The visualization method provides us with three different views: a traditional table view (a), a dynamic graph view (b) and a smartphone view (c).

5.5. Evaluation

The visualization specification and method were implemented within the Avrora electronic health record. The EHR was enabled to construct and show visual medical documents. Physicians operate the desktop version of the system. Patients have access to the data in Internet and information kiosks in the polyclinic building. So the method was tested in the Avrora environment.

```xml
<VisualGroups>
  <VisualGroup GroupID = "VG1">
    <GroupName>BloodTest</GroupName>
    <VisualElements>
      <VisualElement>
        <ElementID>EID1</ElementID>
        <ElementName>Leukocytes</ElementName>
        <ArchetypeID>leukocytes.xml</ArchetypeID>
        <ElementPath>leukocytes</ElementPath>
        <ElementReference>leukocytes-Reference</ElementReference>
        <ElementDataType>PQ</ElementDataType>
        <ElementType>GroupMember</ElementType>
        <OrderInGroup>1</OrderInGroup>
        <Widget>
          <PQ>
          </PQ>
        </Widget>
        <Users>
          <Patient>Patient</Patient>
          <Doctor>Doctor</Doctor>
        </Users>
        <Devices>
          <device>Desktop</device>
        </Devices>
      </VisualElement>
      <VisualElement>...</VisualElement>
    </VisualElements>
  </VisualGroup>
  <VisualGroup GroupID ="VG2">
    <GroupName>Puls</GroupName>
    <VisualElements>
      <VisualElement>...</VisualElement>
    </VisualElements>
  </VisualGroup>
  </VisualGroups>
  <VisualSpec>
    <Report>...</Report>
    <Report>...</Report>
    <LifeLines>...</LifeLines>
    <LifeLines>...</LifeLines>
  </VisualSpec>
</VisualConcept>
```

Fig. 6. Visual group definition.

The visualization module worked in parallel to the EHR system that is already being operated by the health care provider and consists of two main logical parts. The first part is a designer that generates an archetype based visual medical concept in XML format allowing the re-use and sharing of visual concepts. The second part was a module that actually produced the web pages to be shown to the users.

6. Results of the evaluation

After the recruitment process the evaluation study included the following participants: doctors (Table 1) and patients. Doctors and patients were divided into two groups. For doctors the criteria was the experience with Avrora EHR and the patients were divided (Table 2) based on their age (<40 and 40+).

Following figures demonstrate that the data accessibility, cognitive efficiency and learnability of the system have almost reached the expert level (average 39 s to read a medical document by the end of the study) for the patients by the end of the evaluation process (Fig. 8). Fig. 8 shows that during the evaluation study patients learned very quickly how to read medical data from the EHR. The expert curve in Fig. 8 is constant as we have taken our study team average performance as an expert level. This demonstrates a high efficiency and good learnability of the approach. The average level of mistakes is lower for the evaluated system (1 by the end of the study) in comparison to paper-based documents (4 by the end of the study). This shows the high cognitive efficiency of the approach. The average level of mistakes dropped from 5 to 1 during the study (Fig. 9) along with the decrease (from 7 to 4) of the

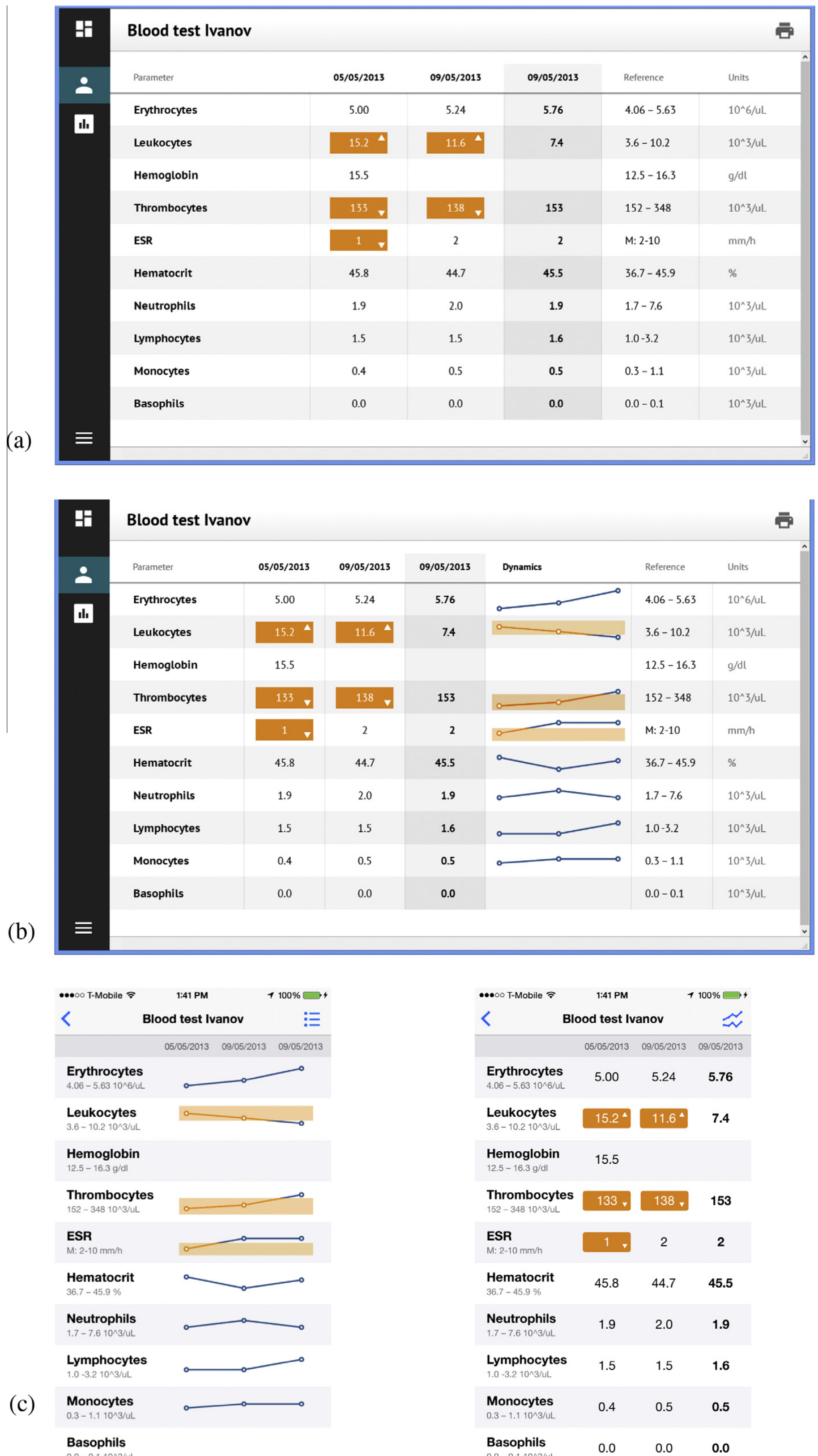

Fig. 7. Different view of the laboratory test results.

average number of operations to complete a task. This proves the high learnability of the approach. This means that the patients' understanding of the EHR data have improved in comparison with both paper based process and the beginning of the study. The relatively low values of the metrics for the first evaluation for all the user groups are caused by the lack of experience of the users. The time of accessing and reading medical data from the computer screen dropped by the end of the evaluation study and

Table 1
Physicians taking part in the evaluation study.

ID	Specialty	EHR experience
1	General practitioner	No
2	General practitioner	No
3	General practitioner	Yes
4	Endocrinologist	No
5	Ophthalmologist	Yes

Table 2
Patients divided into groups by age.

Group	Age	Number of participants	Gender	Education
1	>40	17	11 males, 6 females	11 – higher education (university) 6 – secondary education (secondary school)
2	<40	13	5 males, 8 females	8 – higher education 5 – secondary education

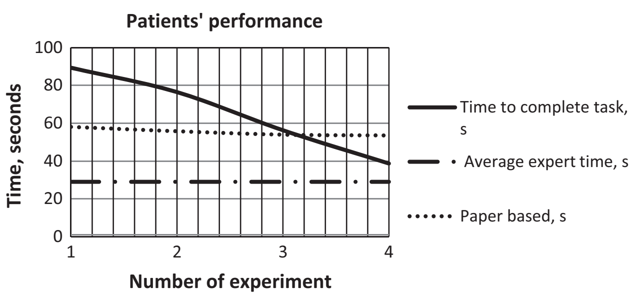

Fig. 8. Average patients' performance indicators.

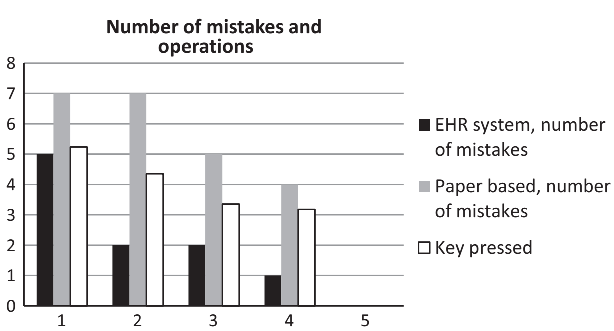

Fig. 9. Average information accessing and processing indicators.

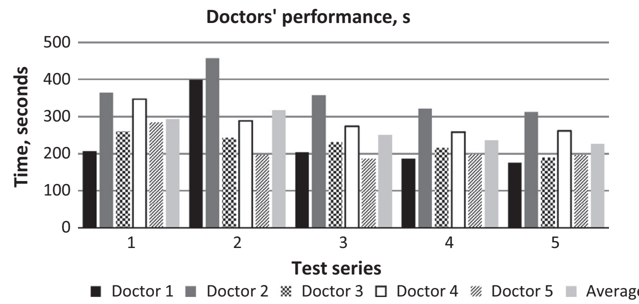

Fig. 10. Physicians' performance. First measurement is a paper-based process.

Fig. 11. Average level of users' satisfaction.

demonstrated the advantage over the traditional paper documents. The time reading paper documents also dropped but only within less than 3%. So the learnability of the system is also very high.

The level of doctors' performance in comparison to paper-based process has also shown the efficiency of the proposed method. Doctors from both groups demonstrated better performance working with the solution. The time to complete a task has dropped from average 316 to 226 s. The paper based process took 292 s in average (Fig. 10). Fig. 10 contains 5 series of tests. The first series is a paper based process that we have measured before all others to compare electronic and paper based process. The doctors commented that they now could spend more time with a patient and trust the EHR system that provides them with more convenient medical documents. The level of satisfaction that has grown from 8.4 to 9.8 (Fig. 11) shows that doctors and patients are satisfied and motivated to use the system in the everyday work process. It has to be mentioned that this is a very subjective criterion; however, it was measured to understand the general perception of the system by the users and there was no high variation in users' estimates. The level of satisfaction has increased during the study as the patients learned how to use the system and had more confidence in the system. Electronic representation of data was the main unsatisfactory point. Firstly patients did not perceive electronic health record as a fully legal substitution to the paper documents. Other unsatisfactory point was that the system did not explain the meaning of the values, only reported if they are normal or not.

The solution has also proved to provide efficient modeling functionality. The performance shown by doctors has dropped from average 498 s in the manual and 346 s in wizard mode to reach the expert level both in wizard (197 s) and manual (374 s) modes (Fig. 12). This proves that the presented visualization approach is easy to learn and covers the main needs of the users.

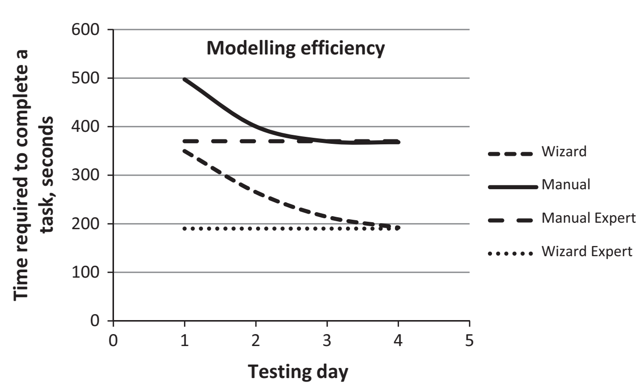

Fig. 12. Average modeling efficiency. Doctors' study.

The study showed that the developed methods provide efficient interfaces to the users. The performance of doctors and patients reached the expert level. It allowed decreasing time of operation the EHR system in comparison with a paper based process and other EHR systems.

In general the evaluation study demonstrates the efficiency of the system for both doctors and patients. It decreases time working with EHR and provides efficient data representation for different user groups. The solution gives users a better control on the system by providing efficient modeling facilities. As users reported it was one of the main motivating factors to use the system, because they could define their own appearance of the documents. The rate of data misinterpretations is very low in comparison with traditional paper based process. This raises the motivation to use EHR system in everyday life.

7. Discussion

Most EHR systems consider only the healthcare professionals' perspective [40–48]. Recent initiatives on the personal health record and patient empowerment address the patient as an active partner of the treatment process [49–53]. A standard based visual tool that was developed and evaluated within our project allows patients accessing their medical record and brings the patient–doctor interaction onto a new level. Even though standard ISO/EN 13606 medical concepts prove beneficial and are a good basis for building user interfaces, visualization methods that are based only on the structure of the data will not provide an optimal presentation layer due to the limitations of the archetype model [54].

Previous studies like the Gastros project [12] and the PropeR project [13] proposed data visualization based on the ADL structure of archetypes. The previous studies could generate visual representation only on the archetypes can derive only their structure: composition, element, entry and a data type [12,13].

In this work we advanced the state of the art studies on the visualization of standard based medical data by introducing a dual model approach. We have developed an XML schema for the ISO 13606 archetype model. This allowed developing an XML based visual medical concept to enable multi-user and multimedia definition of the presentation properties on the stage of EHR instance modeling in form of XML instances. The newly developed approach is based on the idea that a visual layer completes the archetype layer, which represents the medical concept. The visual medical concepts define platform independent visual blocks and the layout for each archetype data field, respecting also the archetype structure. Visual medical concept provides a comprehensive data model and supports on the model level flexible constructing visual medical documents, considering different user roles and media. It allows processing several archetypes and composing complex medical documents. In comparison with the previous studies the presented approach not only allows standard data representations for archetype fields but provides a comprehensive model for multirole and multimedia interface definitions. The introduced model allows overcoming the barriers of the archetype model that were faced in the previous studies [12,13] on archetype data visualization. It allows automatic generation of efficient medical data user interfaces based. This was proved by the evaluation study.

Unfortunately the previous projects did not report how the developed systems were evaluated. So we cannot compare the results of the evaluation. However, all the previous projects reported that the presentation that the automatically generated medical data interfaces were suboptimal and required manual adjusting.

On one hand side it preserves the advantages of the state of the art technologies. It is generic and supports changes in data sets. On the other side it provides a wider functionality for a precise GUI definition. Users can specify all the standard visualization properties (color, size, font and others) and group archetype data according to their requirement.

The evaluation study proved that the developed solution gives users a better control over the system by providing efficient modeling facilities. As users reported it was one of the main motivating factors to use the system, because they could define their own appearance of the documents.

The developed visualization method is based on the idea of processing standard XML visual medical concepts that store the specification of the visual document. They contain both content and layout. This provides the possibility to implement the method in different EHR systems. The reusable visual medical concepts can be replicated among different EHR systems to allow processing of the medical data received from the archetype based systems. As has been shown and evaluated in this work the barriers of adoption are very low.

The goal of this paper was to propose, develop, implement and evaluate an information model and a specification for building a user interface for archetype based medical data. This was a step towards achieving the objective of semantic interoperability on the visual level.

8. Conclusion

The introduced visual medical concept allows separating medical knowledge expressed in ISO 13606 archetypes and presentation knowledge defined in the visual medical concepts on the model level. The visual content model considers standard data fields' associations.

The implemented web-application showed a high potential of the developed models and specifications. The visual documents' generator allows constructing medical documents on the time of medical concept (archetype) implementation. The proof of concept implementation used XSL templates to present medical data as web pages. XSL templates were used to highlight the approach that only standard based tools were used to implement the proof of concept application.

The wide implementation of the standard based solutions will help to make a step towards standardized data visualization concepts.

The evaluation of the proposed approached in a clinical environment proved its efficiency. A month of intensive testing with doctors and patients showed the flexibility and convenience of the developed tools for different user groups and different media. The evaluation showed the reduction of time working with medical documents and decreasing of the level of misinterpretation of medical data even for automatically generated interfaces.

Conflict of interest

None declared.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jbi.2015.04.009.

References

[1] S. Garde, E. Hovenga, J. Buck, P. Knaup, Expressing clinical data sets with openEHR archetypes: a solid basis for ubiquitous computing, Int. J. Med. Inform. 76 (Suppl. 3) (2007) S334–341.
[2] G. Duftschmid, T. Wrba, C. Rinner, Extraction of standardized archetyped data from electronic health record systems based on the entity-attribute-value model, Int. J. Med. Inform. 79 (2010) 585–597.
[3] P. Kaushik, S.S. Intille, K. Larson, User-adaptive reminders for home-based medical tasks. A case study, Methods Inf. Med. 47 (2008) 203–207.
[4] M.A. Johansen, G. Berntsen, N. Shrestha, J.G. Bellika, J.A. Johnsen, An exploratory study of patient attitudes towards symptom reporting in a primary care setting. Benefits for medical consultation and syndromic surveillance?, Methods Inf Med. 50 (2011) 479–486.
[5] G. Gigerenzer, Making sense of health statistics, Bull. World Health Organ. 87 (2009) 567.
[6] S. Faisal, A. Blandford, H.W. Potts, Making sense of personal health information: challenges for information visualization, Health Inform. J. 19 (2013) 198–217.
[7] N. Gershon, S.G. Eick, S. Card, Information visualization, Interactions 5 (1998) 9–15.
[8] S.K. Card, J. Mackinlay, The structure of the information visualization design space, in: IEEE Symposium on Information Visualization, 1997 Proceedings, 21–21 October 1997, 1997, pp. 92–99.
[9] W.T. Goossen, A. Goossen-Baremans, Bridging the HL7 template – 13606 archetype gap with detailed clinical models, Stud. Health Technol. Inform. 160 (2010) 932–936.
[10] C. Martinez-Costa, M. Menarguez-Tortosa, J.T. Fernandez-Breis, Towards ISO 13606 and openEHR archetype-based semantic interoperability, Stud. Health Technol. Inform. 150 (2009) 260–264.
[11] K. Bointner, G. Duftschmid, HL7 template model and EN/ISO 13606 archetype object model – a comparison, Stud. Health Technol. Inform. 150 (2009) 249.
[12] K. Atalag, H.Y. Yang, From openEHR domain models to advanced user interfaces: a case study in endoscopy, in: 2010 Health Informatics New Zealand Conference, Wellington, 2010.
[13] H. van der Linden, T. Austin, J. Talmon, Generic screen representations for future-proof systems, is it possible? there is more to a GUI than meets the eye, Comput. Meth. Programs Biomed. 95 (2009) 213–226.
[14] K.J. Cios, G.W. Moore, Uniqueness of medical data mining, Artif. Intell. Med. 26 (2002) 1–24.
[15] T. Fonseca, C. Ribeiro, C. Granja, Vital signs in intensive care: automatic acquisition and consolidation into electronic patient records, J. Med. Syst. 33 (2009) 47–57.
[16] A. Maciel, G. Sankaranarayanan, T. Halic, V.S. Arikatla, Z. Lu, S. De, Surgical model-view-controller simulation software framework for local and collaborative applications, Int. J. Comput. Assist. Radiol. Surg. 6 (2011) 457–471.
[17] B. Blobel, Architectural approach to eHealth for enabling paradigm changes in health, Methods Inf. Med. 49 (2010) 123–134.
[18] R.I. Bull, Model Driven Visualization: Towards a Model Driven Engineering Approach for Information Visualization, University of Victoria, 2008.
[19] G. Kopanitsa, Standard based multiclient medical data visualization, Stud. Health Technol. Inform. 180 (2012) 199–203.
[20] G. Kopanitsa, C. Hildebrand, J. Stausberg, K.H. Englmeier, Visualization of medical data based on EHR standards, Methods Inf. Med. 52 (2013) 43–50.
[21] H. Muller, A. Hanbury, N. Al Shorbaji, Health information search to deal with the exploding amount of health information produced, Methods Inf. Med. 51 (2012) 516–518.
[22] H. van der Linden, T. Schuler, R. Chen, J. Talmon, Generic screen representations for future proof systems–is it possible? two-model approach to a generic GUI, Stud. Health Technol. Inform. 129 (2007) 1122–1126.
[23] A. McKinlay, C. McVittie, E. Reiter, Y. Freer, C. Sykes, R. Logie, Design issues for socially intelligent user interfaces a discourse analysis of a data-to-text system for summarizing clinical data, Methods Inform. Med. 49 (2010) 379–387.
[24] R. Chen, G. Enberg, G.O. Klein, Julius–a template based supplementary electronic health record system, BMC Med. Inform. Decis. Mak. 7 (2007) 10.
[25] S. Sun, T. Austin, D. Kalra, A data types profile suitable for use with ISO EN 13606, J. Med. Syst. 36 (2012) 3621–3635.
[26] M.P. Gagnon, N. Shaw, C. Sicotte, L. Mathieu, Y. Leduc, J. Duplantie, J. Maclean, F. Legare, Users' perspectives of barriers and facilitators to implementing EHR in Canada: a study protocol, Implement Sci. 4 (2009) 20.
[27] J. Goedert, Wishing for a better EHR: electronic health records users share their wish lists for added functionality, Health Data Manage. 16 (2008). 26–28, 30, 32 passim.
[28] J.B. Smelcer, H. Miller-Jacobs, L. Kantrovich, Usability of electronic medical records, J. Usability Stud. 4 (2009) 15.
[29] R.L. Edsall, K.G. Adler, The 2012 EHR User Satisfaction Survey: responses from 3088 family physicians, Fam. Pract. Manage. 19 (2012) 23–30.
[30] L. Bird, C. Brooks, Y.C. Cheong, N.N. Tun, A logical approach to semantic interoperability in healthcare, Stud. Health Technol. Inform. 168 (2011) 1–9.
[31] G. Kopanitsa, Evaluating study for a multiuser oriented medical data visualization method, Stud. Health Technol. Inform. 197 (2014) 123.
[32] G. Kopanitsa, Z. Tsvetkova, H. Veseli, Analysis of metrics for the usability evaluation of EHR management systems, Stud. Health Technol. Inform. 180 (2012) 358–362.
[33] G. Kopanitsa, Z. Tsvetkova, H. Veseli, Analysis of metrics for the usability evaluation of electronic health record systems, Stud. Health Technol. Inform. 174 (2012) 129–133.
[34] P. Nykanen, J. Brender, J. Talmon, N. de Keizer, M. Rigby, M.C. Beuscart-Zephir, E. Ammenwerth, Guideline for good evaluation practice in health informatics (GEP-HI), Int. J. Med. Inform. 80 (2011) 815–827.
[35] P. Nykanen, J. Brender, E. Ammenwerth, J. Talmon, M. Rigby, Applying GEP-HI for the planning of an evaluation study: a case study walkthrough (workshop), Stud. Health Technol. Inform. 174 (2012) 134–136.
[36] A. Faxvaag, P. Toussaint, T.S. Johansen, Research management in healthcare informatics – experiences from Norway, Stud. Health Technol. Inform. 169 (2011) 980–984.
[37] A.C. Atkinson, A.N. Donev, R.D. Tobias, Optimum Experimental Designs, with SAS, Oxford University Press, Oxford, 2007.
[38] A. McKinlay, C. McVittie, E. Reiter, Y. Freer, C. Sykes, R. Logie, Design issues for socially intelligent user interfaces. A discourse analysis of a data-to-text system for summarizing clinical data, Methods Inf. Med. 49 (2010) 379–387.
[39] H. Veseli, G. Kopanitsa, H. Demski, Standardized EHR interoperability – preliminary results of a German pilot project using the archetype methodology, Stud. Health Technol. Inform. 180 (2012) 646–650.
[40] E.L. Abramson, V. Patel, S. Malhotra, E.R. Pfoh, S. Nena Osorio, A. Cheriff, C.L. Cole, A. Bunce, J. Ash, R. Kaushal, Physician experiences transitioning between an older versus newer electronic health record for electronic prescribing, Int. J. Med. Inform. 81 (2012) 539–548.
[41] Y. Bar-Dayan, H. Saed, M. Boaz, Y. Misch, T. Shahar, I. Husiascky, O. Blumenfeld, Using electronic health records to save money, J. Am. Med. Inform. Assoc. 20 (2013) e17–20.
[42] J.D. Bramble, K.A. Galt, M.V. Siracuse, A.A. Abbott, A. Drincic, K.A. Paschal, K.T. Fuji, The relationship between physician practice characteristics and physician adoption of electronic health records, Health Care Manage. Rev. 35 (2010) 55–64.
[43] T. Christensen, A. Grimsmo, Instant availability of patient records, but diminished availability of patient information: a multi-method study of GP's use of electronic patient records, BMC Med. Inform. Decis. Mak. 8 (2008) 12.
[44] W.O. Hackl, A. Hoerbst, E. Ammenwerth, "Why the hell do we need electronic health records?". EHR acceptance among physicians in private practice in Austria: a qualitative study, Methods Inf. Med. 50 (2011) 53–61.
[45] D. Klimov, Y. Shahar, M. Taieb-Maimon, Intelligent interactive visual exploration of temporal associations among multiple time-oriented patient records, Methods Inf. Med. 48 (2009) 254–262.
[46] H.J. Lanham, L.K. Leykum, R.R. McDaniel Jr., Same organization, same electronic health records (EHRs) system, different use: exploring the linkage between practice member communication patterns and EHR use patterns in an ambulatory care setting, J. Am. Med. Inform. Assoc. 19 (2012) 382–391.
[47] T. Le, B. Reeder, H. Thompson, G. Demiris, Health providers' perceptions of novel approaches to visualizing integrated health information, Methods Inf. Med. 52 (2013) 250–258.
[48] C.A. McGinn, S. Grenier, J. Duplantie, N. Shaw, C. Sicotte, L. Mathieu, Y. Leduc, F. Legare, M.P. Gagnon, Comparison of user groups' perspectives of barriers and facilitators to implementing electronic health records: a systematic review, BMC Med. 9 (2011) 46.
[49] W. Kuijpers, W.G. Groen, N.K. Aaronson, W.H. van Harten, A systematic review of web-based interventions for patient empowerment and physical activity in chronic diseases: relevance for cancer survivors, J. Med. Internet Res. 15 (2013) e37.
[50] R.D. White, Patient empowerment and optimal glycemic control, Curr. Med. Res. Opin. 28 (2012) 979–989.
[51] I. Lejbkowicz, O. Caspi, A. Miller, Participatory medicine and patient empowerment towards personalized healthcare in multiple sclerosis, Expert Rev. Neurother. 12 (2012) 343–352.
[52] C. Meyer, A. Muhlfeld, C. Drexhage, J. Floege, E. Goepel, P. Schauerte, M. Kelm, T. Rassaf, Clinical research for patient empowerment – a qualitative approach on the improvement of heart health promotion in chronic illness, Med. Sci. Monit. 14 (2008) CR358–365.
[53] S. Kumar, Client empowerment in psychiatry and the professional abuse of clients: where do we stand?, Int J. Psychiatry Med. 30 (2000) 61–70.
[54] C. Rinner, S. Janzek-Hawlat, S. Sibinovic, G. Duftschmid, Semantic validation of standard-based electronic health record documents with W3C XML schema, Methods Inf. Med. 49 (2010) 271–280.